CHAPTER II.

ON-ROAD HEAVY-DUTY VEHICLES

This chapter presents the project criteria for on-road heavy-duty vehicles under the Carl Moyer Program. It also contains a brief overview of the heavy-duty vehicle industry, NOx emission inventory, current emission standards, available control technology, potential projects eligible for funding, and emission reduction and cost-effectiveness calculation methodologies.

A. Introduction

Vehicles greater than 14,000 pounds gross vehicle weight rating (GVWR) are considered heavy-duty vehicles. Heavy-duty vehicles can be categorized as heavy heavy-duty (HHD) and medium heavy-duty (MHD) vehicles. Heavy heavy-duty vehicles are those greater than 33,000 pounds GVWR and are grouped under a "class 8" truck classification. Medium heavy-duty vehicles are those greater than 14,000 but less than or equal to 33,000 pounds GVWR and comprised of classes 4 through 7 trucks. The majority of all heavy-duty vehicles are powered by diesel engines.

The preference for diesel engines presents an air quality challenge since emissions from diesel engines have not been able to be controlled to the same extent as gasoline vehicles, particularly light- and medium-duty vehicles. Furthermore, heavy-duty diesel vehicles involved in goods movement applications typically accrue higher annual mileage than other vehicles. Consequently, the share of emissions, particularly of NOx and PM, from heavy-duty diesel vehicles is disproportionately higher than their population would suggest. The Carl Moyer Program provides financial incentives to assist in the purchase of cleaner heavy-duty vehicles, including urban buses, to achieve additional near-term emission reductions from these sources.

1. Emission Inventory

In California, on-road mobile sources account for about 50 percent of total NOx emissions. Even though heavy-duty diesel vehicles, including urban buses, account for less than two percent of all on-road vehicles, they emitted about 25 percent of the statewide NOx emissions and over 70 percent of the exhaust PM emissions from all on-road vehicles in 1998. Heavy-duty diesel vehicles emitted 424 tons per day (tpd) of NOx and 26 tpd of exhaust PM emissions statewide. In addition, vehicle miles traveled from heavy-duty vehicles are projected to increase by about 30 percent by 2010. Emissions from heavy-duty diesel vehicles have to be reduced further if air quality goals are to be achieved.

2. Emission Standards

Adopted emission standards have reduced NOx and PM emissions from heavy-duty vehicles substantially. Furthermore, NOx emissions from new heavy-duty vehicles will be cut in half starting in 2004 as a result of recently adopted regulations. Table II-1 lists the existing and future NOx and PM emission standards for heavy-duty engines.

Table II-1
Exhaust Emission Standards for Heavy-Duty Engines

Model Year	NOx and PM Emission Standards (g/bhp-hr)[a]			
	Heavy-Duty Vehicles		Urban Buses	
	NOx	PM	NOx	PM
1996 - 2003	--	--	4.0	0.05 [b]
1998 - 2003	4.0	0.10	--	--
2004 +	2.4 [c] or 2.5 [d]	0.10	2.4[c] or 2.5[d]	0.05[b]

[a] g/bhp-hr = grams per brake-horsepower-hour
[b] in-use standard of 0.07 g/bhp-hr
[c] NOx plus Non-Methane Hydrocarbons (NMHC)
[d] NOx plus NMHC with 0.5 g/bhp-hr NMHC cap

The Carl Moyer Program provides incentives to obtain additional emission reductions immediately by encouraging the purchase and deployment of reduced-emission heavy-duty vehicles. Alternative fuel and advanced technology engines can provide significant emission reductions for on-road vehicles. There are several MHD and HHD reduced-emission engine technologies available in the California marketplace.

3. Control Technologies

This section discusses commercially available reduced-emission engines for MHD and HHD vehicles. The engines discussed are considered suitable as new engine/vehicle purchase, or new engine purchases for vehicle repower opportunities. Also discussed briefly are emerging technologies that may be commercially available in two to three years. The information in this section is intended to provide information regarding reduced-emission engine technologies that can be purchased now, and technologies, which have potential to become commercially available in the near term. These technologies are most likely available for the Carl Moyer Program funding. A program criterion for the Carl Moyer Program is that the engines be certified. Some engines discussed below have not been certified to the ARB's optional NOx emission credit standards. However, they are included in this discussion since they could potentially be certified to those standards during the time frame of the Carl Moyer Program.

a. <u>Available Technologies</u>

Diesel engines, due to their high efficiency and long life, dominate the MHD and HHD vehicle market. However, due to their lean-burn operation, they have had limitations in achieving significant NOx emission reductions. Currently, alternative fuel engines, especially compressed natural gas (CNG) and liquefied natural gas (LNG) engines have been able to achieve NOx emissions about half of a conventional diesel engine. In addition to CNG and LNG engines, dual-fuel engines are also available for heavy-duty truck applications. Alternative fuel engines, including liquid petroleum gas (LPG) engines, are also available for medium heavy-duty truck application. Engine manufacturers have invested a considerable amount of resources in the research and development of reduced-emission diesel engines and progress is being made, especially with the integration of advanced electronics and greater use of exhaust gas recirculation. However, it is expected that within the time frame of the Carl Moyer Program, the only new vehicles that will be able to demonstrate the requisite emission reduction will be alternative fuel vehicles.

The variety of alternative fuel engines available, and the number sold, has increased significantly in the past five years. The number and variety of engines continues to expand. Alternative fuel vehicles have made the most progress in the transit bus market. At this time, more than 20 percent of all bus sales in California are alternative fuel and several transit agencies have a policy of exclusively buying alternative fuel buses. These include Sacramento Metropolitan Regional Transit Authority, Los Angeles County Metropolitan Transportation Authority, and Sunline Transit. Current district incentive programs have been instrumental in maturing this market.

Dual-fuel engines are available that are certified to reduce NOx to about 60 percent of the required NOx standards. One set of in-use test data shows that while these engines deliver full emission benefits in many applications, the emission benefits are less for engines operated on a low-speed, stop-and-go chassis cycle (the Central Business District cycle). One indication of this is the percentage of alternative fuel consumed. This fuel substitution rate has been high (approximately 80%) during certification, but may be significantly lower in stop-and-go applications. ARB staff has been working closely with a dual-fuel engine manufacturer to collect additional information and more accurately determine the emission benefits in neighborhood refuse collection. Prior to any dual-fuel project being funded for a stop-and-go application, the manufacturer must provide the Executive Officer with data demonstrating that the fuel substitution rate is appropriate for natural gas versus diesel.

b. Emerging Technologies

Several low-emission technologies hold promise for the future, but are not yet commercially available. Some of these technologies include aqueous fuel, ceramic coating, and high-pressure direct injection natural gas. These technologies may be developed as engine retrofit or new engine technologies, but, at the present time, they are not certified for sale in California to reduced-emission levels. Some of these emerging/experimental technologies may not be able to be certified during the tenure of this program. These technologies would be ineligible to participate in the Carl Moyer Program since the ARB's policy is to provide funding only for reduced-emission engines or technologies that have been certified. However, for very promising technologies that have sufficiently demonstrated their potential to reduce emissions, ARB could grant, on a case-by-case basis, an experimental permit for an engine with certain technology to operate in California. Experimental permits are typically granted for demonstrations involving one or two vehicles, and include very strict limitations. For example, the allowed time for operating a vehicle with an experimental-permitted engine is usually limited to one or two years, after which the engine has to be removed from service, unless an extension is requested and is justified. The ARB intends experimental permits to be a means to field test a technology in some limited situations and not to be a way to circumvent certification requirements.

Even though these emerging technologies may not be commercially available during the current Carl Moyer Program, an on-going incentive program would likely provide the impetus that could expedite the development of these technologies and encourage research and development into additional technologies. Promising longer-term technologies, such as fuel-cell or hybrid powerplants, could potentially qualify for partial funding under the program, if they comply with the program criteria and are certified for sale, or have been granted an experimental permit subject to the limitations discussed above. However, since these technologies are currently too expensive for a project to meet the cost-effectiveness criterion, a cost buy-down would likely be needed.

Alternative Diesel Fuels: Over the years industry has produced various alternative diesel fuels (i.e., diesel water emulsions, bio-diesel, etc.) that may lower PM and NOx emissions from diesel engines, as compared to conventional diesel. Some of these technologies are emerging from the demonstration stage to a commercial product, while others are still in the research stage. As such, ARB staff has been evaluating whether or not to consider alternative diesel fuels that are entering into the commercial market as a potential category for reducing emissions under the Carl Moyer Program.

The Carl Moyer Program is designed to reduce emissions by applying control technology (engine hardware) that has been certified beyond the current standards. In essence, it is a program aimed at providing the end users with an incentive to clean up their very old engines by replacing them with newer engines that have cleaner control technology. Under the current Carl Moyer Program, associated program reductions are easily measured and enforced. Engine technology is typically certified for sale in California by ARB, tested according to regulatory test procedures, and has warranties on components that reduce emissions. Hence the program provides real, quantifiable, and enforceable emission reductions statewide.

Allowing alternative diesel fuel as a category under the Carl Moyer Program may be viable in the future. However, some issues still need to be evaluated by staff before this option is routinely allowed under the Carl Moyer Program. First, allowing this category would require ARB to move from a program that is currently focused on updating old engines (hardware), to a program that would allow diesel engines to remain in operation by simply changing over to an alternative diesel fuel. The manufacturer of the alternative diesel would need to demonstrate that the fuel is cleaner than conventional diesel fuel.

The Carl Moyer program is designed to calculate emission reductions and cost-effectiveness based on actual usage (i.e., mileage, fuel consumption, or hours of operation) and the cost difference between engine technology. Although there may be a cost difference between the alternative diesel fuel and conventional diesel fuel, tracking fuel consumption for the alternative diesel fuel may be difficult. Currently, there is no method for assuring that an alternative diesel fuel is being used over conventional diesel, since vehicles may be able to continue operating on either fuel.

AB 2061, signed by the Governor, appropriated $500,000 to be used for alternative diesel fuels. ARB staff has developed interim test procedures to evaluate the emission benefits of these alternative diesel fuels. Until final procedures are approved, funding for alternative diesel fuel projects will be allowed on a case-by-case basis based on the incremental cost between the two fuels.

Funding for the incremental cost of alternative fuels (if any) will also be allowed on a case-by-case basis. However the alternative fuels must be used with a Carl Moyer qualified project. ARB staff, in cooperation with the district, will evaluate the project to determine whether or not it will qualify for funds based on emission benefits and cost-effectiveness. Furthermore, funding of incremental fuel costs for alternative fuel projects is optional for districts. If funded by the district, these funds would count as a district's matching funds under the Carl Moyer Program.

Hybrid Electric Vehicles: Hybrid buses utilize an electric drive typically with an internal combustion engine (diesel or alternative-fuel) and a traction battery. Current California and federal certification test procedures are based on non-hybrid engine duty-cycles and therefore are not able to adequately represent the emissions benefits of the hybrid technology. Diesel hybrid vehicle projects would only be approved on a case-by-case basis at an emission level deemed appropriate by ARB. ARB staff would determine the emissions benefits for buses based on the chassis Central Business District Cycle. Additional information may be used based on the operating regime of the engine in the particular hybrid system.

c. Incentives for Early Replacement of Pre-1987 Heavy-Duty Vehicles

Pre-1987 heavy-duty diesel trucks still comprise a significant portion of the truck population in California. The engines in these trucks are continuing to be rebuilt since the truck owners/operators typically do not have the financial resources to buy newer trucks. These vehicles typically operate from California's ports to densely populated areas and back. They also operate around-the-clock, and, on a seasonal basis, hauling agricultural products, as well as other non-line haul local deliver applications.

ARB staff understands the need to reduce emissions from this segment of the heavy-duty diesel truck sector. In fact, ARB considered a similar program to retire heavy-duty engines in the past. However, the analysis indicated that the older, high emitting trucks removed from the fleet were not likely to be replaced with cleaner vehicles, but rather with trucks of similar age from outside the area, providing little or no emission benefit. Also, the prospects for a self-funded program diminished when the anticipated overseas market for old California trucks did not materialize. Therefore with the lack of expected emissions benefit and funding, the heavy-duty engine retirement program was never implemented.

Staff conducted another analysis to determine potential benefits associated with providing incentives for the early replacement of pre-1987 heavy-duty engines. This analysis is provided in Appendix A. Based on this analysis, staff was not able to develop a cost-effective program. Therefore, Carl Moyer Program funding is not allowed for the early replacement of pre-1987 heavy-duty vehicles with newer, but used, heavy-duty vehicles.

B. Project Criteria

The project criteria for on-road heavy-duty vehicles provide districts, fleet operators, and transit agencies with the minimum qualifications that must be met for a project to qualify for funding. The main criteria for selecting a project are the amount of emission reductions, cost-effectiveness, and ability for the project to be completed within the timeframe of the program. These criteria will also provide districts and program operators with calculations that must be used for determining emission reductions and cost effectiveness resulting from reduced-NOx on-road heavy-duty vehicle projects. Reduced-NOx on-road heavy-duty vehicle projects, which include new vehicle purchase, vehicle engine replacement (repower), and engine retrofit, will be considered and evaluated for incentive funding. In general, on-road heavy-duty vehicle projects qualifying for evaluation must meet the criteria listed below. The criteria includes new project life for on-road heavy-duty vehicle engine projects based on the remaining amount of useful life for the older engine and is listed for new purchases and repower projects.

- Eligible projects must provide at least 30 percent NOx emission reduction (for new vehicle purchases) compared to baseline NOx emissions. For repower or retrofit projects, the retrofit kit must be certified to reduce NOx emissions by at least 15 percent;

- NOx reductions obtained through this program must not be required by any existing regulations, memoranda of agreement/understanding, or other legally binding documents;

- Reduced-emission engines or retrofit kits must be certified for sale in California and must comply with durability and warranty requirements. Qualified engines could include new ARB-certified engines; ARB-certified aftermarket part engine/control devices; or engines with ARB-approved experimental permits;
- Funded projects must operate for a minimum of 5 years and at least 75 percent of vehicle annual miles traveled must occur in California; and

- Projects must meet a cost-effectiveness criterion of $13,000 per ton of NOx reduced.

- The maximum acceptable project life for calculating on-road project benefits is as follows:

	Default without Documentation	Default with Documentation
School buses $\geq$ 33,000 GVWR – New	20 years	N/A
Buses $\geq$ 33,000 GVWR – New	12 years	N/A
Other On-road – New	10 years	15 years
Other On-road – Repowers	7 years	15 years

Project life beyond the "default without documentation" may be selected for approval by ARB staff. However sufficient documentation must be provided to ARB that supports the selected project life based on the actual remaining useful life.

C. Potential Types of Projects.

The primary focus of the Carl Moyer Program is to achieve emission reductions from heavy-duty vehicles operating in California as early and as cost-effectively as possible. The project criteria were designed to ensure that the emission reductions expected through the deployment of low-emission engines or retrofit technologies under this program are real, quantifiable, and enforceable.

1. New Vehicles

New vehicle purchases of LNG and CNG trucks and buses are expected to be the most common type of project for on-road heavy-duty vehicles under this program. In order to be eligible to participate in this program, the new vehicle/engine has to be certified to one of the ARB's current optional NOx emission credit standards, regardless of fuel type or engine design. The ARB NOx emissions credit standards start at 2.5 g/bhp-hr and decrease in 0.5 g/bhp-hr increments. Engines not certified to the ARB's NOx emission credit standards are not eligible to participate in the Carl Moyer Program even if the engines were certified at levels similar to, or could have been certified at, the credit levels. Table II-2 lists the current heavy-duty engines that have been certified to the ARB's optional NOx emission credit standards. Since new engines are certified throughout the year, districts are encouraged to contact ARB staff for the most current list of eligible engines.

Table II-2
Heavy-Duty Engines Certified to
ARB's Optional NOx Emission Credit Standards
(Emission Levels for NOx, PM, and NMHC are in g/bhp-hr)

MY	Manuf.	Service Type [a]	Fuel Type	Displ (ltr)	NOx	PM	NMHC	Cert. Std. NOx/PM	HP
2000	Baytech	MHD	Dual [b]	5.7	1.3	--	0.00[c]	1.5/NA	211/245[d]
2000	Baytech	MHD	CNG	5.7	1.3	--	0.00	1.5/NA	211
2000	Baytech	HDG	CNG	5.7	1.3	--	0.00	1.5/NA	211
2000	Baytech	HDG	Dual [b]	5.7	1.3	--	0.00[c]	1.5/NA	211/245[d]
2000	Cummins	MHD	LPG	5.9	2.3	0.01	--	2.5/0.10	195
2000	Cummins	MHD	L/CNG	5.9	1.8	0.02	0.1	2.5/0.10	150/195/230
2000	Cummins	HHD	CNG	8.3	1.837	0.02	0.6	2.5/0.10	250/275
2000	Cummins	UB	CNG	8.3	1.7	0.02	0.6	2.5/0.05	250/275
2000	DDC	UB	L/CNG	12.7	2.0	0.02	0.8	2.5/0.05	330
2000	DDC	UB	L/CNG	8.5	1.5	0.01	0.8	2.0/0.05	275
2000	Deere	MHD	CNG	8.1	2.2	0.02	0.4	2.5/0.10	225/250
2000	Deere	MHD	CNG	6.8	2.4	0.04	0.3	2.5/0.10	225
2000	IMPCO	MHD	LPG	7.4	0.8	--	0.66	1.5/NA	229
2000	Mack	HHD	L/CNG	11.9	2.3	0.03	0.3	2.5/0.1	325/350
2000	PSA	MHHD	Dual[e]	7.2	2.2	0.08	1.2	2.5/0.10	200/240/250
2000	PSA	HHD	Dual[e]	10.3	2.4	0.06	1.1	2.5/0.10	305/350
2000	PSA	HHD	Dual[e]	12.0	2.4	0.10	0.5	2.5/0.10	370/410
1999	Deere	MHD	CNG	6.8	2.4	0.04	0.3	2.5/0.10	225
1999	Deere	MHD	CNG	8.1	2.2	0.02	0.4	2.5/0.10	250
1999	DDC	UB	CNG	12.7	2.0	0.02	0.8	2.5/0.05	330

1999	DDC	UB	CNG	8.5	2.2	0.01	0.6	2.5/0.05	275
1999	Cummins	UB	L/CNG	10.0	1.4	0.02	0.03	2.0/0.05	280/300
1999	Cummins	HHD	L/CNG	8.3	1.8	0.02	0.6	2.5/0.10	250/275
1999	Cummins	UB	L/CNG	8.3	1.7	0.01	0.2	2.5/0.05	250/275
1999	Cummins	MHD	L/CNG	5.9	1.8	0.02	0.1	2.5/0.10	150/195/230
1999	Cummins	MHD	LPG	5.9	2.3	0.01	0.8[f]	2.5/0.10	195
1999	IMPCO	MHD	LPG	7.4	0.8	--	0.66	1.5/N/A	229
1999	PSA[g]	MHD	Dual[e]	7.1	2.4	0.09	1.0	2.5/0.10	200
1999	PSA[g]	MHD	Dual[e]	7.2	2.2	0.07	1.2	2.5/0.10	250
1999	PSA[g]	MHD	Dual[e]	7.2	2.4	0.09	1.0	2.5/0.10	200
1999	PSA[g]	HHD	Dual[e]	10.3	2.4	0.06	1.1	2.5/0.10	305/350
1999	PSA[g]	HHD	Dual[e]	12.0	2.4	0.10	0.5	2.5/0.10	370/410

[a] Service Type: MHD (Medium Heavy-Duty); HHD (Heavy Heavy-Duty); UB (Urban Bus)
[b] Dual fuel (CNG or gasoline)
[c] NMHC: 0.00 for CNG; 0.2 for gasoline
[d] Horsepower: 211 for CNG; 245 for gasoline
[e] Dual Fuel (CNG + Diesel; or LNG + Diesel)
[g] Power Systems Associates (using Caterpillar engine)

As evident from Table II-2, only alternative fuel engines are currently certified to the ARB's optional NOx emission credit standard. The Carl Moyer Program is fuel neutral for all project categories. Purchases of new transit buses must be beyond the requirements of ARB's Urban Transit Bus Rule.

2. Repowers

Vehicle repower refers to replacing an older engine with a newer engine certified to lower emission standards. There may be limited opportunities to repower on-road vehicles with new engines. One area where this may be cost-effective to do is in replacing an old mechanical engine with a newer model year mechanical engine that is certified to a lower NOx emission standard. Mechanical engines are those engines having their injection timing mechanically controlled and are most common for pre-1991, and particularly for pre-1987, model year engines. Since certain mechanical engine families share similar engineering designs they could be replaced with another mechanical engine in some cases.

For the purpose of the Carl Moyer Program, eligible heavy-duty diesel-to-diesel truck repower projects are those that replace uncontrolled mechanical engines with emission controlled mechanical engines. For mechanical-to-mechanical engine repowers, an applicant must provide the district with the VIN number, engine model number, and serial number for ARB to determine if the project would qualify for funding. Electronic-to-electronic engine repowers are allowed only when replacing a 1988 and later model year electronic engine with an engine manufactured on or after October 1, 2002. Post 1987 repower projects are allowed for projects where a diesel engine is repowered with an alternative fuel engine.

Under the Carl Moyer Program, funding is not available for projects where spark-ignition engines (i.e., natural gas or gasoline, etc.) are replaced with new diesel engines.

A few districts have expressed an interest to allow mechanical-to-electronic engine repowers for on-road heavy-duty engines. Although substantial NOx emissions may occur by repowering a pre-1987 mechanical engine with an engine manufactured on or after October 1, 2002, the electronically controlled engines are difficult to install in applications that were not previously electronically controlled. The fuel system and electrical system for these engines are completely different compared to a mechanical engine. Mechanical-to-electronic engine repowers are allowed only on a case-by-case basis. ARB, in cooperation with the local air district, will evaluate the project and determine if the benefits are adequate to merit funding under the Carl Moyer Program.

3. Retrofits

Retrofit means making modifications to the engine and/or fuel system such that the retrofitted engine does not have the same specifications as the original engine. Retrofit projects are allowed for all engine model years. The most straightforward retrofit projects are those that could be done at the time of engine rebuild. This might entail upgrading certain engine and/or fuel system components to result in a lower emission configuration. To qualify for funding for these types of projects, the engine retrofit kit must be certified to reduce NOx emissions by at least 15 percent compared to the original engine certification level.

4. Sample Application

In order to qualify for incentive funds, districts make applications available and solicit bids for reduced-emission projects from heavy-duty vehicle operators and transit agencies. A sample application form is included in Appendix C. The applicant must provide at least the following information, as listed in Table II-3.

Table II-3 **Minimum Application Information** **On-road Projects**	
1. Air District 2. Applicant Demographics Company Name: Business Type: Mailing Address: Location Address: Contact Number: 3. Project Description Project Name: Project Type: Vehicle Function: Vehicle Class: GVWR(lbs): 4. NOx Reduction Incremental Cost Effectiveness Analysis Basis: (Mileage/Fuel/Hours of Operation) 5. VIN or Serial Number: 6. Application: (Repower, Retrofit or New) 7. NOx Emissions Reductions Baseline NOx Emissions Factor: NOx Conversion Factors Used: Reduced NOx Emissions Factor: Estimated Annual NOx Emissions Reductions: Estimated Lifetime NOx Emissions Reductions: 8. Percent Operated in California:	9. Annual Diesel Gallons Used: 10. Annual Miles Traveled: 11. Hours of Operation: 12. Project Life (years): 13. Old Engine Information Horsepower Rating: Engine Make: Engine Model: Engine Year: 14. New Engine Information Horsepower Rating: Engine Make: Engine Model: Engine Year: Fuel Type: 15. Cost ($) of the Base Engine: 16. Cost ($) of Certified LEV Engine: 17. District Incentive Amount Requested: 18. PM Emissions Reductions Baseline PM Emissions Factor: PM Conversion Factors Used: Reduced PM Emissions Factor: Estimated Annual PM Emissions Reductions: Estimated Lifetime PM Emissions Reductions:

D. Emission Reduction and Cost Effectiveness

1. Emission Reduction Calculation.

In general, the emission reduction benefit represents the difference in the emission level of a baseline and reduced-emission vehicle/engine. In situations where the model year of the vehicle chassis and the model year of the existing engine are different, the model year of the engine will be used to determine the baseline emission factor for emission reduction calculations. The emission level is calculated by multiplying an emission factor, an activity level and a conversion factor, if necessary. Because the conversion factor and the activity level could be different for the baseline and reduced emission vehicle/engine, the emission level should be calculated first and then the difference taken to determine the emission reduction. The examples in the February 1999 Carl Moyer Program Guidelines, where the emission reductions were simply based on the difference in emission factors, assumed that there was no change in the conversion factor or activity level. For most on-road vehicles the activity level is defined by the annual miles traveled as indicated by the vehicle odometer. Refuse vehicles operating in predominantly stop and go applications, however, are the exception. In this case, the activity level should be based on fuel consumed as specified by actual annual fuel receipts or other documentation. Emission reduction calculations shall be consistent with the type of records maintained over the life of the project.

The NOx emission factors have been updated to reflect the recently adopted EMFAC2000 emissions model, which accounts for the settlement agreement between USEPA, ARB and the diesel engine manufacturers (regarding excess NOx emissions from the use of alternative injection timing strategies). EMFAC2000 emission factors are based on chassis dynamometer test data that are in units of g/mile. The model year NOx emission factor listed in Tables II-4, II-5, and II-6 represent the bag 2 zero mile emission factors of medium heavy-duty vehicles, heavy heavy-duty vehicles, and urban buses, respectively. School buses should use the emission factor according to their GVWR.

If annual mileage is the basis for emission reductions, a conversion factor may be needed to convert g/bhp-hr to g/mile units. The conversion factors listed in Table II-7 should be used as default.

Table II-4
NOx Emission Factors for Medium Heavy-Duty Vehicles
14,001 – 33,000 lbs GVWR

Model Year	Grams per Mile
Pre - 1983	18.5
1984 - 1986	17.9
1987 - 1990	15.7
1991 - 1993	13.1
1994 - 1997	11.5
1998 - 2002	10.5
2003 +	5.5

Table II-5
NOx Emission Factors for Heavy Heavy-Duty Vehicles
33,000 + lbs GVWR

Model Year	Grams per Mile
Pre - 1975	28.5
1975 - 1983	27.2
1984 - 1986	20.2
1987 - 1990	16.8
1991 - 1993	16.0
1994 - 1997	19.1
1998	23.0
1999 – 2002	13.4
2003 +	6.7

Table II-6
NOx Emission Factors
for Urban Buses

Model Year	Grams per Mile
Pre – 1987	46.2
1987 – 1990	40.2
1991 – 1993	25.5
1994 – 1995	29.8
1996 – 1998	39.2
1999 – 2002	20.4
2003	10.2
2004 – 2006	2.5
2007	1.0

Table II-7 Diesel Equivalent Conversion Factors for Heavy-Duty Vehicle Projects (bhp-hr/mile)			
Model Year	**Medium Heavy-Duty Diesel 14001-33,000 lbs.**	**Heavy Heavy-Duty Diesel 33000 lbs. +**	**Urban Transit Bus [a] 33000 lbs. +**
Pre-1978	2.3	2.9	4.3
1978 – 1981	2.3	2.8	4.3
1982 – 1983	2.3	2.8	4.3
1984 – 1990	2.3	2.7	4.3
1991 – 1995	2.3	2.7	4.3
1996+	2.3	2.6 [b]	4.3

a. Urban transit buses over 33,000 gross vehicle weight rating (GVWR) or school buses over 33,000 GVWR in an urban area.
b. 2.6 bhp-hr/mile is for all heavy-duty line haul trucks (class 8).

Refuse vehicles operating predominantly in stop-and-go applications accrue low mileage yet intermittently operate at high load during compaction mode. Therefore, a g/mile emission factor may not be appropriate for these operating conditions. Furthermore, based on discussion with engine manufacturers, neighborhood refuse collection trucks are subject to limited off-cycle emissions. ARB staff estimates that a typical heavy-duty diesel truck performing neighborhood waste collection activities would have off-cycle emissions 20 percent of the time. The model year NOx emission factors for refuse vehicles operating predominantly in stop and go applications are listed in Table II-8. An applicant may use the gram per mile emission factors on a case-by-case basis, provided sufficient documentation is provided to ARB showing that the vehicle/fleet do not operate under these conditions.

Table II-8 NOx Emission Factors for Refuse Vehicles Predominantly in Stop-and-Go Applications	
Model Year	**g/bhp-hr**
Pre – 1987	10.0
1987 – 1990	6.0
1991 - 1998	5.2
1999 - 2002	4.4
2003 +	2.5

If annual fuel consumption is the basis for the emission reductions, an energy consumption factor is used to convert g/bhp-hr to g/gallon of fuel used. Heavy-duty diesel engines typically have a brake-specific energy consumption of 6,500 to 7,000 BTU per horsepower-hour on the certification cycle. Diesel fuel has an energy density of about 18,000 BTU/lb and a mass density of 7.0 lb/gallon. This results in an energy consumption factor of about 18.5 horsepower-hour/gallon of fuel consumed, which should be used as the default for refuse vehicles operating predominantly in stop-and-go applications. Otherwise, there are two ways of calculating an engine specific energy consumption factor: 1) divide the horsepower of the engine by the fuel economy in units of gallons/hour or 2) divide the density of the fuel by the brake-specific fuel consumption of the engine. While actual fuel receipts or other documentation support the annual fuel consumption of the baseline engine, the annual fuel consumption of the reduced-emission engine is an estimate proportion to the change in the energy consumption factor. For example, a reduced-emission engine having an energy consumption factor of 18.5, replacing a baseline engine which uses 5,000 gallons/year, and which has an energy consumption factor of 17.8, would have an estimated annual fuel consumption of 5,197 gallons/year. Future fuel receipts or equivalent documentation should be submitted annually, throughout the project life, as verification of this estimate.

New emission factors may prevent some diesel-to-diesel repower projects from qualifying for funding. Therefore, the emission reduction requirement has been modified to 15 percent.

2. Cost-Effectiveness Calculations

For new heavy-duty vehicle purchase projects, only the incremental cost of purchasing a new vehicle that meets the optional NOx emission credit standard compared to a conventional vehicle that meets the existing NOx emission standard, will be funded through the Carl Moyer Program. For vehicle repower projects, the portion of the cost for a vehicle repower project to be funded through the Carl Moyer Program is the difference between the total cost of purchasing and installing the new, emission-certified engine and the total cost of rebuilding the existing engine. For engine retrofit projects, the full cost of the retrofit kit will be funded subject to the $13,000 per ton cost-effectiveness criterion. For Urban Transit Buses, the portion of the capital cost to be funded through the Carl Moyer Program is the non-FTA funds (20 percent of full capital cost) and is subject to the $13,000 per ton cost-effectiveness criterion.

Full incremental cost for an urban transit bus could be granted, however, on a case-by-case basis. The transit district must demonstrate a true need. The transit district would need to provide ARB with its Transportation Implementation Plan (TIP) and any annual updates. If data included in the TIP is not sufficient for ARB to determine the need for the applicant to receive full incremental cost, ARB would ask for additional documentation. The costs that are not considered eligible for Carl Moyer funds include operating costs such as maintenance or other “life-cycle” costs.

Only the amount of money provided by the program and any local district matching fund is to be used in cost-effectiveness calculations. The one-time incentive grant amount is to be amortized over the expected project life (at least five years) and with a discount rate of five percent. The amortization formula (given below) yields a capital recovery factor, which, when multiplied by the initial capital cost, gives the annual cost of a project over its expected lifetime.

Capital Recovery Factor (CRF) = $[(1 + i)^n (i)] / [(1 + i)^n – 1]$

Where,

i = discount rate (5 percent)
n = project life (at least five years)

The discount rate of five percent reflects the opportunity cost of public funds for the Carl Moyer Program. This is the level of earning that could be reasonably expected by investing state funds in various financial instruments, such as U.S. Treasury securities. Cost-effectiveness is determined by dividing the annualized cost by the annual NOx emission reductions. Example calculations for on-road vehicle projects are provided below.

3. Examples

For the purposes of explaining the emission reduction and the cost effectiveness calculations from a heavy-duty engine project, three examples are presented below.

Example 1 – Diesel to Diesel On-Road Repower (Calculations based on Mileage). A line haul trucking company proposes to repower a 1983 heavy heavy-duty diesel line haul truck with a model year 1990 certified NOx diesel engine. This vehicle operates 90% of the time in California.

Emission Reduction Calculation

Baseline NOx Emission factor:	27.2 g/mile
Reduced NOx Emission factor:	16.8 g/mile
Annual Miles:	60,000 miles
% Operated in CA:	90%
Convert grams to tons:	ton/907,200g

Hence, the estimated reductions are:
(27.2 g/mile – 16.8 g/mile) * 60,000 mile/year * 90% * ton/907,200 g =
0.62 tons/year NOx emissions reduced

Cost and Cost-Effectiveness Calculations

The annualized cost is based on the portion of incremental project costs funded by the Carl Moyer Program, any matching funds that were used to fund the project, the expected life of the project (7 years default life for heavy-duty truck repowers), and the interest rate (5 percent) used to amortize the project cost over the project life. The incremental capital cost to the fleet operator for this purchase and the maximum amount that could be funded through the Carl Moyer Program fund are determined as follows:

Incremental Capital Cost:	$ 30,000 - $ 7,000 (for rebuild) = $ 23,000
Maximum Amount Funded:	$ 23,000
Capital Recovery:	$[(1 + 0.05)^7 (0.05)]/[(1 + 0.05)^7 – 1] = 0.17$
Annualized Cost:	(0.17)($ 23,000) = $ 3,910/year
Cost-Effectiveness:	($ 3,910/year)/(0.62 tons/year) **= $ 6,306/ton**

The cost effectiveness for the example is less than $13,000 per ton of NOx reduced. This project would qualify for the maximum amount of grant funds requested.

Example 2 – Diesel to Diesel On-Road Repower (Calculations based on Mileage). A refuse company proposes to repower a 1970 heavy heavy-duty diesel transfer truck with a model year 1990 certified NOx diesel engine. This vehicle operates 100% of the time in California.

<u>Emission Reduction Calculation</u>

Baseline NOx Emission factor:	28.5 g/mile
Reduced NOx Emission factor:	16.8 g/mile
Annual Miles:	120,000 miles
% Operated in CA:	100%
Convert grams to tons:	ton/907,200g

Hence, the estimated reductions are:

(28.5 g/mile – 16.8 g/mile) * 120,000 mile/year * 100% * ton/907,200 g =
1.5 tons/year NOx emissions reduced

<u>Cost and Cost-Effectiveness Calculations</u>

The annualized cost is based on the portion of incremental project costs funded by the Carl Moyer Program, any matching funds that were used to fund the project, the expected life of the project (7 years default life for heavy-duty truck repowers), and the interest rate (5 percent) used to amortize the project cost over the project life. The incremental capital cost to the fleet operator for this purchase and the maximum amount that could be funded through the Carl Moyer Program fund are determined as follows:

Incremental Capital Cost:	$ 25,000 - $ 4,000 (for rebuild) = $ 21,000
Maximum Amount Funded:	$ 21,000
Capital Recovery:	$[(1 + 0.05)^7 (0.05)]/[(1 + 0.05)^7 – 1] = 0.17$
Annualized Cost:	(0.17)($ 21,000) = $ 3,570/year
Cost-Effectiveness:	($ 3,570/year)/(1.5 tons/year) **= $ 2,380/ton**

The cost effectiveness for the example is less than $13,000 per ton of NOx reduced. This project would qualify for the maximum amount of grant funds requested.

Example 3 – CNG New Vehicle Purchase (Calculations Based on Fuel Consumption). A refuse collection company proposes to purchase a new CNG vehicle versus a diesel one with a

GVWR 58,000 lbs. This vehicle is used for door-to-door refuse pick-up and operates 100% of the time in California.

Emission Reduction Calculation

Baseline NOx Emission factor:	4.4 g/bhp-hr
Reduced NOx Emission factor:	2.5 g/bhp-hr
Conversion Factor:	18.5 bhp-hr/gal
Annual Fuel Consumption:	10,400 gal/year
% Operated in CA:	100 %
Convert grams to tons:	ton/907,200 g

Hence, the estimated reductions are:
(4.4 g/bhp-hr - 2.5 g/bhp-hr) * 18.5 bhp-hr/gal * 10,400 gal/year * 100% * ton/907,200 g =
0.40 tons/year NOx emissions reduced

Cost and Cost-Effectiveness Calculations

The annualized cost is based on the portion of incremental project costs funded by the Carl Moyer Program, any matching funds that were used to fund the project, the expected life of the project (10 years for heavy-duty trucks), and the interest rate (5 percent) used to amortize the project cost over the project life. The incremental capital cost to the fleet operator for this purchase and the maximum amount that could be funded through the Carl Moyer Program fund are determined as follows:

Incremental Capital Cost:	\$ 135,000 - \$ 90,000 = \$ 45,000
Maximum Amount Funded:	\$ 45,000
Capital Recovery:	$[(1 + 0.05)^{10} (0.05)]/[(1 + 0.05)^{10} - 1] = 0.13$
Annualized Cost:	(0.13)(\$ 45,000) = \$ 5,850/year
Cost-Effectiveness:	(\$ 5,850/year)/(0.40 tons/year) **= \$ 14,625/ton**

The cost-effectiveness for the example is greater than the \$13,000 per ton cost-effectiveness requirement. In order to meet the \$13,000 per ton cost-effectiveness requirement, this project would only qualify for part of the incremental cost – a maximum amount of \$40,450.

Example 4 – Urban Bus Purchase. A transit agency proposes to purchase a new CNG bus instead of a new diesel bus. The costs of a CNG bus and a diesel bus are \$350,000 and \$310,000, respectively. The new bus will operate 100 percent of the time in California.

Emission Reduction Calculation

Baseline NOx Emission factor:	20.4 g/mile
Reduced NOx Emission factor:	2.0 g/bhp-hr
Conversion Factor:	4.3 bhp-hr/mile
Annual Miles:	50,000 miles
% Operated in CA:	100 %
Convert grams to tons:	ton/907,200 g

Hence, estimated annual NOx reductions are:
[(20.4 g/mile) – (2.0 g/bhp-hr * 4.3 bhp-hr/mile)] * 50,000 miles/year * 100% * ton/907,200 g =
0.65 tons/year NOx emissions reduced

Cost and Cost-Effectiveness Calculations

The annualized cost is based on the portion of incremental project costs funded by the Carl Moyer Program, any matching funds that were used to fund the project, the expected life of the project (12 years for urban bus), and the interest rate (5 percent) used to amortize the project cost over the project life. For urban bus purchases, the Federal Transit Administration (FTA) pays approximately 80% of the cost of a new transit bus. The incremental capital cost to the transit agency for this purchase and the maximum amount that could be funded through the Carl Moyer Program fund are determined as follows:

FTA Grant for purchase of new diesel bus:	(0.8)($ 310,000) = $ 248,000
Transit agency's cost for new diesel bus:	$ 310,000 - $ 248,000 = $ 62,000
FTA Grant for purchase of new CNG bus:	(0.8)($ 350,000) = $ 280,000
Transit agency's cost for new CNG bus:	$ 350,000 - $ 280,000 = $ 70,000
Incremental Capital Cost:	$ 70,000 - $ 62,000 = $ 8,000
Max. Amount Funded:	$ 8,000
Capital Recovery Factor:	$[(1 + 0.05)^{12} (0.05)]/[(1 + 0.05)^{12} – 1] = 0.11$
Annualized Cost:	(0.11)($ 8,000) = $ 880/year
Cost-Effectiveness:	($ 880/year)/(0.65 tons/year) **= $ 1,354/ton**

The cost effectiveness for the example is less than $13,000 per ton of NOx reduced. This project would qualify for the maximum amount of grant funds requested – the incremental cost of what was not funded by FTA. Once again, full incremental cost for an urban transit bus would be granted, on a case-by-case basis. The transit district must demonstrate a true need by providing ARB with its Transportation Implementation Plan (TIP) and any annual updates. If data included in the TIP is not sufficient for ARB to determine the need for the applicant to receive full incremental cost, ARB would ask for addition documentation. Operating costs such as maintenance or other "life-cycle" costs are not funded under the Carl Moyer Program.

Example 5 – Street Sweeper (Calculations Based on Fuel Consumption). A city municipality proposes to buy a CNG street sweeper in 2001 instead of a diesel street sweeper. The main engine for the proposed street sweeper will be a CNG engine that is certified to the optional NOx standard of 2.5 g/bhp-hr, while the auxiliary engine will be an off-road diesel engine certified to a NOx standard of 6.9 g/bhp-hr. This vehicle is operated entirely within the city's limit in California. Based on historical fuel usage, the main engine of the street sweeper uses approximately two-thirds of the total fuel consumed with the remaining one-third attributable to the auxiliary engine. The cost of a new CNG street sweeper is $162,000 compared to $122,000 for a new diesel powered street sweeper

Emission Reduction Calculation

Baseline NOx Emission factor:	4.4 g/bhp-hr
Reduced NOx Emission factor:	2.5 g/bhp-hr
Conversion Factor:	18.5 bhp-hr/gal

Annual Fuel Consumption: 5,300 gal/year
% Operated in CA: 100 %
Convert grams to tons: ton/907,200 g

Hence, the estimated reductions are:

Main Engine:

(4.4 g/bhp-hr - 2.5 g/bhp-hr) * 18.5 bhp-hr/gal * 5,300 gal/year *(2/3)* 100% * ton/907,200 g = **0.14 tons/year NOx emissions reduced**

Auxiliary Engine:

(6.9 g/bhp-hr – 6.9 g/bhp-hr) * 18.5 bhp-hr/gal * 5,300 gal/year *(1/3)* 100% * ton/907,200 g = **0 ton/year NOx emissions reduced**

Total Emission Reductions: 0.14 + 0 = 0.14 tons/year NOx emiss. reduced

Cost and Cost-Effectiveness Calculations

The annualized cost is based on the portion of incremental project costs funded by the Carl Moyer Program, any matching funds that were used to fund the project, the expected life of the project (10 years for heavy-duty trucks), and the interest rate (5 percent) used to amortize the project cost over the project life. The incremental capital cost to the fleet operator for this purchase and the maximum amount that could be funded through the Carl Moyer Program fund are determined as follows:

Incremental Capital Cost: $ 162,000 - $ 122,000 = $ 40,000
Maximum Amount Funded: $ 40,000
Capital Recovery: $[(1 + 0.05)^{10} (0.05)]/[(1 + 0.05)^{10} – 1] = 0.13$
Annualized Cost: (0.13)($ 40,000) = $ 5,200/year
Cost-Effectiveness: ($ 5,200/year)/(0.14 tons/year) **= $ 37,143/ton**

The cost-effectiveness for the example is greater than the $13,000 per ton cost-effectiveness requirement. In order to meet the $13,000 per ton cost-effectiveness requirement, this project would only qualify for part of the incremental cost – a maximum amount of $12,924.

E. Reporting and Monitoring.

The district has the authority to conduct periodic checks or solicit operating records from the applicant that has received Carl Moyer funds for new heavy-duty vehicle purchase, vehicle repowering, or engine retrofit projects. This is to ensure that the vehicle or engine is operated as stated in the program application. Fleet operators and transit agencies participating in the Carl Moyer Program are required to keep appropriate records during the life of the funded project. Records must contain, at a minimum, total miles traveled and California miles traveled, amount of fuel used, and maintenance and repair information. Records must be retained and updated throughout the project life and made available at the request of the district.